Subject: CONVENTIONAL BENDING MAGNETS FOR STORAGE RING (II)

Aperture Considerations

As mentioned in TM-44, other options that determine the aperture would be developed. The following discusses the option in which a full aperture kicker is employed and no phase plane interchange is used in the transfer from the main accelerator to the storage ring. As before, the beam emittances listed in the 200 GeV accelerator Design Report are altered by the momentum ratio for 100 GeV.

Beam Emittance in Main Accelerator

$$E_H = .23 \times \frac{200.94}{100.93} \pi = .458\ \pi \text{ mm-mrad},$$

$$E_V = .09 \times \frac{200.94}{100.93} \pi = .179\ \pi \text{ mm-mrad}.$$

Beam Emittance After Transport Channel

Assume a dilution factor of 2 in transfer.

$$E_H = 2 \times .458\ \pi = .916\ \pi \text{ mm-mrad},$$

$$E_V = 2 \times .179\ \pi = .358\ \pi \text{ mm-mrad}.$$

Three-Turn Radial Injection into Storage Ring

$$E_H = (2 + \tfrac{1}{3})^2 \times .916\ \pi = 4.987\ \pi \text{ mm-mrad},$$

$$E_V = .358\ \pi \text{ mm-mrad}.$$

Lattice Functions

As before divide the bending magnets between QF and QD into four magnets to reduce the effects of sagitta. Using SYNCH run FOD5 (MacLachlan 10/3/68)

	QF	B11	B12	B21	B22	QD
β_H(m)	39.55	36.98	29.40	22.13	16.99	10.27
β_V(m)	10.20	16.91	22.04	29.29	36.83	39.40
X_p(m)	2.18	2.11	1.88	1.65	1.48	1.20

Beam Radii

Let a_H and a_V designate the beam radii of a single-turn beam in the storage ring. Let A_H designate the beam radius of a radially injected three-turn beam. Let ΔX designate the radial beam size occupied by the momentum spread Δp. Then, using $a = (\beta E/\pi)^{\frac{1}{2}}$ and $\Delta p/p = \pm 10^{-3}$, one finds

	QF	B11	B12	B21	B22	QD
a_H(mm)	6.02	5.82	5.19	4.50	3.94	3.07
a_V(mm)	1.91	2.46	2.81	3.24	3.63	3.76
A_H(mm)	14.04	13.58	12.11	10.51	9.20	7.16
ΔX(mm)	±2.18	±2.11	±1.88	±1.65	±1.48	±1.20

Closed Orbit and Gradient Errors

Assuming rms errors of

$$\Delta B/B = \Delta L_{MAG}/L_{MAG} = \Delta\Theta_{MAG} = 5 \times 10^{-4},$$

and

$$\Delta X(\text{QUAD}) = \Delta Y(\text{QUAD}) = 10^{-4} \text{ m.}$$

$$\langle V_H \rangle = \frac{2x63}{4x1/2} \cdot \left(\frac{2.1x20}{3366.8}\right)^2 \cdot (36.98 + 29.40 + 22.13 + 16.99)$$

$$x(25x10^{-8} + 25x10^{-8}) + \frac{63}{4x1/2} \cdot \left(\frac{348x10^{-4}}{3366.8}\right)^2 \cdot (39.55 + 10.27)$$

$$= 68.48 \times 10^{-8} \text{ m.}$$

$$\langle V_V \rangle = \frac{2\text{x}63}{4\text{x}1/2} \cdot \left(\frac{2.1\text{x}20}{3366.8} \right)^2 \cdot (16.91 + 22.04 + 29.29 + 36.83)$$

$$\text{x } (25\text{x}10^{-8} + 25\text{x}10^{-8}) + \frac{63}{4\text{x}1/2} \cdot \left(\frac{348\text{x}10^{-4}}{3366.8} \right)^2 \cdot (10.20 + 39.40)$$

$$= 68.20\text{x}10^{-8} \text{ m.}$$

For gradient errors use, $\delta B' = .01B'$.

Then

$$\langle \delta\nu^2 \rangle = \frac{63}{4\pi^2} \cdot \left(\frac{.01\text{x}348}{3366.8} \right)^2 \cdot \left[(10.20)^2 + (39.40)^2 \right]$$

This gives

$$\delta\nu = .0531$$

and

$$\Delta\beta/\beta = \pi \text{ x } .0531/1.0 = .1670$$

With 50 percent probability, the closed-orbit deviation is less than (1.15) $\sqrt{\beta \langle V \rangle}$.

Hence, one has

	QF	B11	B12	B21	B22	QD
Closed Orbit						
H (mm)	±5.99	±5.79	±5.16	±4.48	±3.92	±3.05
V (mm)	±3.03	±3.90	±4.46	±5.14	±5.76	±5.96
Growth						
H (mm)	±1.13	±1.09	±.97	±.84	±.74	±.57
V (mm)	±.15	±.20	±.23	±.26	±.29	±.30

Sagitta

$$(2.1)^2/8\text{x}168.449 = .00327 \text{ m} = 3.27 \text{ mm}$$

Radial Aperture and Space Occupied by Beam

The radial aperture is determined by

$$\text{Aperture} = 2a_H + 2(A_H + \Delta X + \text{CO(H)} + \text{Growth (H)})$$
$$+ \text{ Sagitta} + \text{Septum Thickness.}$$

Take the septum thickness to be 2mm.

For the vertical beam space

$$\text{Beam Space} = 2\, a_V + 2\left(\text{CO(V)} + \text{Growth (V)}\right).$$

	QF	B11	B12	B21	B22	QD
Apertures						
Radial (mm)	63.99	62.05	55.89	49.23	43.83	35.37
Vertical (mm)	10.18	13.12	15.00	17.28	19.36	20.04

Vacuum Chamber Space

Allow 6 mm total for vertical space occupied by the vacuum chamber and the thermal insulation necessary for baking out.

Required Magnet Apertures

	GOOD FIELD WIDTH (in)	VERT. GAP (in)
QF	2.519	.637
B11	2.443	.753
B12	2.200	.827
B21	1.938	.917
B22	1.726	.998
QD	1.393	1.025
For construction choose		
B1	2.500	1.000
B2	2.000	1.250

Space Charge Limit

$\langle \beta(H) \rangle = 23.67$ m.

$\langle \beta(V) \rangle = 22.03$ m.

$\langle Xp \rangle = 1.56$ m.

$$a = \sqrt{4.987 \times 23.67} + 1.56 = 12.42 \text{ mm.}$$

$$b = \sqrt{.358 \times 22.03} = 2.81 \text{ mm.}$$

$$\left\langle 1/H^2 \right\rangle = 1/2 \left(\frac{1}{(19.4\ )^2} + \frac{1}{(25.75)^2} \right) \ ; \ H = 21.91 \text{ mm.}$$

$$\left\langle 1/G^2 \right\rangle = \frac{1}{2 \times 1.78} \left(\frac{1}{(25.4)^2} + \frac{1}{(31.75)^2} \right); \ G = 37.42 \text{ mm.}$$

$$N \text{ (Incoh.-Transv.)} = 1.25 \times 10^{15} \text{ particles}$$

Magnet Design

As in TM-44 only a rough design is made at this time pending a modification in POLPAR and POLCNTR. Experience with the booster magnet design is used to determine pole widths.

Allowed Quadrupole and Sextupole Tolerances

A gradient H_y' in the bending magnets introduces a betatron tune shift of

$$\Delta\nu = \frac{2 \times 63 \times 2.1\ H_y'}{4\pi \times 168.449 \times 20} (16.91+22.04+29.29+36.83) = .66\ H_y'$$

For $\Delta\nu = .1$

$$H_y' = .152 \text{ kG/m}$$

At the location for which the semi-infinite condenser yields the gradient just determined, one finds ($H_y'' = \pi H_y'/G$)

$$H_y''\ (B_1) = 19 \text{ kG/m}^2,$$

$$H_y''\ (B_2) = 15 \text{ kG/m}^2.$$

These are taken to be the maximum quadrupole and sextupole effects introduced by the bending magnet.

Pole Widths

Using the semi-empirical procedures indicated in TM-44, the pole widths are taken to be

$$W(B_1) = 5.5''$$

$$W(B_2) = 5.5''$$

Results

Table I includes the magnet design data for the option described here. Simple magnetic circuit calculations using C1010 steel have been used to estimate the required excitations. Note that one coil surrounds two magnets. Figures 1 and 2 show the magnet and coil cross sections for the case described.

TABLE I. STORAGE RING MAGNET PARAMETERS

	B_{11}	B_{12}	B_{21}	B_{22}
Magnet Length (m)	2.1	2.1	2.1	2.1
B_o at Magnet Center (kG)	20.0	20.0	20.0	20.0
B' at Good Field Edge (kG/m)	.152	.152	.152	.152
B" at Good Field Edge (kG/m^2)	19	19	15	15
Magnet Width (in)	21.25	21.25	21.25	21.25
Magnet Height (in)	14.25	14.25	15.75	15.75
Pole Width (in)	5.5	5.5	5.5	5.5
Magnet Gap (in)	1.00	1.00	1.25	1.25
Good Field Width (in)	2.50	2.50	2.00	2.00
Coil Window Width (in)	4.125	4.125	4.125	4.125
Coil Window Height (in)	6.75	6.75	8.25	8.25
Coil Turns	40		50	
Conductor Width (in)	.750		.750	
Conductor Height (in)	.750		.750	
Conductor Hole Dia. (in)	.375		.375	
Conductor Corner Radius (in)	.0625		.0625	
Spacing Between Cond. (in)	.0625		.0625	
Conductor Current (A)	1169		1169	
Resistance (Ohms)	.0243		.0304	
Power (kW)	33.2		41.6	
Inductance (H)	.0424		.0530	
Stored Energy (kJ)	29.0		36.2	
Cooling Water Press. (psi)	200.		200.	
No. Water Paths/Coil	4		5	
Water Temp. Rise (^oC)	9.3		9.3	
Magnet Iron Weight (lbs)	5594	5594	6013	6013
Copper Coil Weight (lbs)	2154	2154	2693	2693
Stacked Beam Sp. Ch. Lim. (10^{15})	1.25			

Total Mag. Wt. (2 Rings - Tons)	2925
Total Copper Wt. (2 Rings - Tons)	611
Total Power (2 Rings - MW)	18.9
Total Stored Energy (2 Rings - MJ)	16.4
Total Water Flow (2 Rings - GPM)	7703

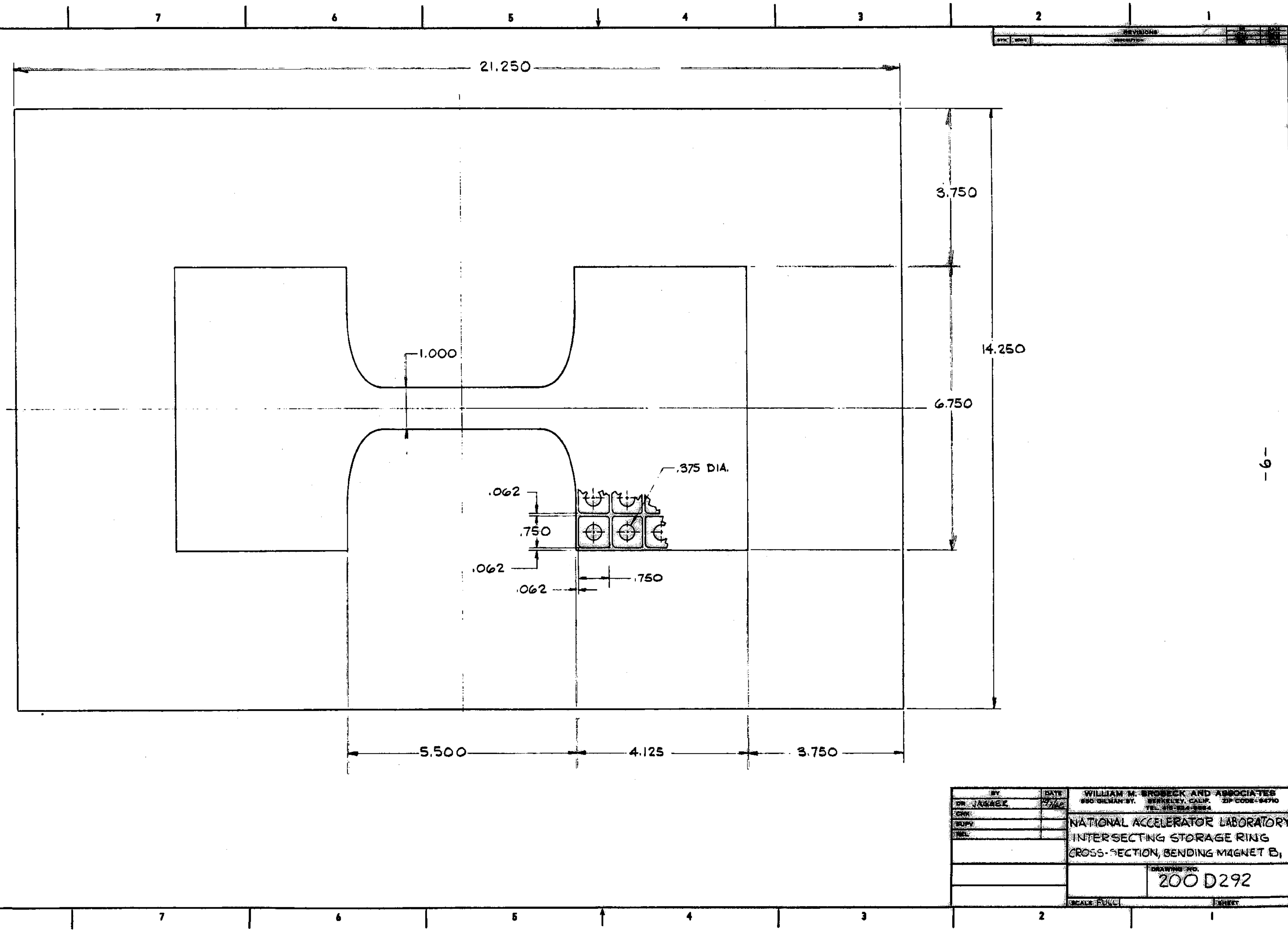
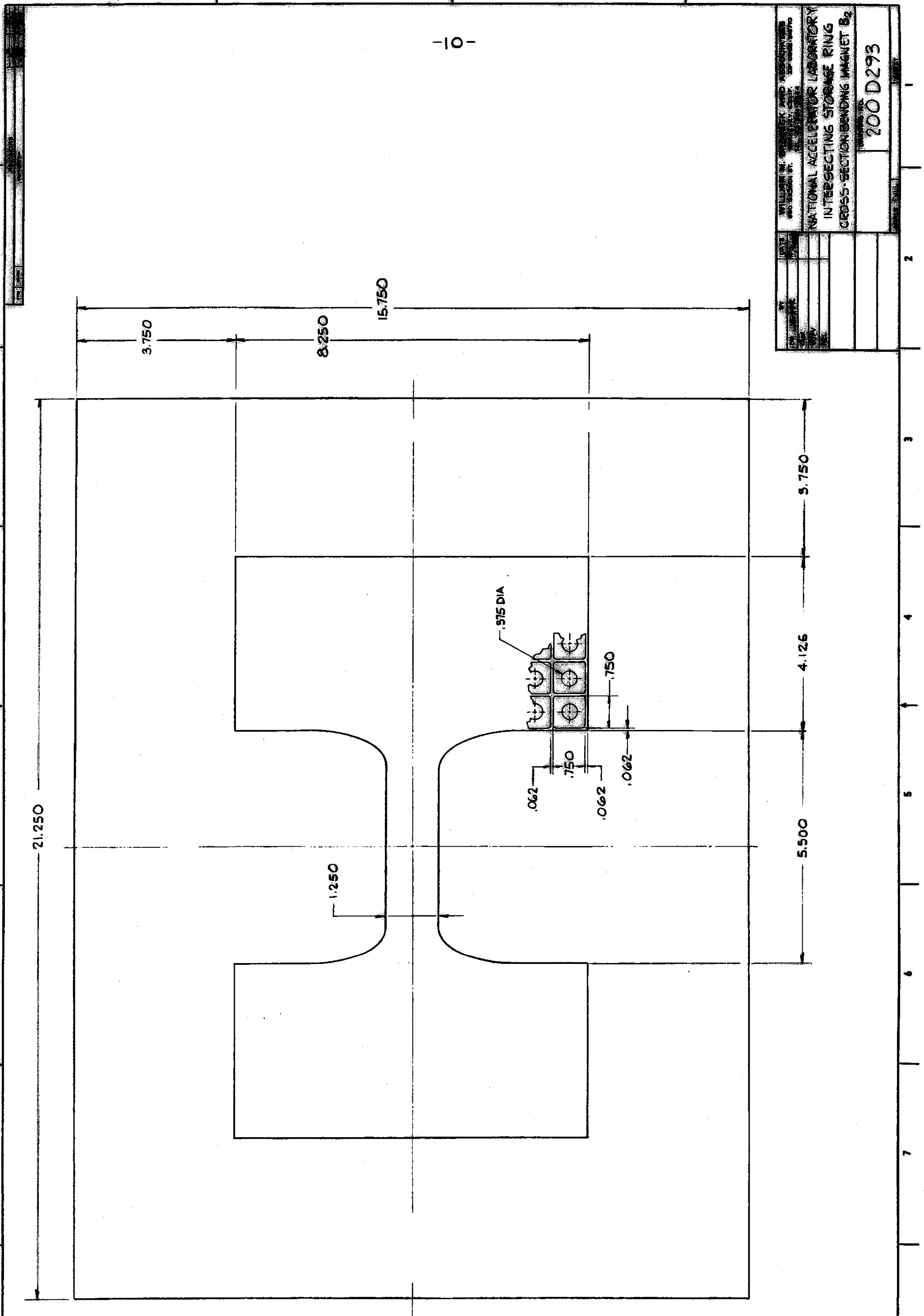

21.250
14.250
3.750
6.750
1.000
.375 DIA.
.062
.750
.062
.062
.750
5.500
4.125
3.750
WILLIAM M. BROBECK AND ASSOCIATES
NATIONAL ACCELERATOR LABORATORY
INTERSECTING STORAGE RING
CROSS-SECTION, BENDING MAGNET B1
DR. JAGGER
DRAWING NO.
200 D292
SCALE FULL
REVISIONS

FIG. 1



NATIONAL ACCELERATOR LABORATORY
INTERSECTING STORAGE RING
CROSS-SECTION BENDING MAGNET B_2
200 D293
15.750
3.750
8.250
21.250
3.750
4.126
5.500
1.250
.375 DIA
.750
.062
.750
.062
.062

FIG. 2